

HEAT REJECTION FROM A VARIABLE CONDUCTANCE HEAT PIPE RADIATOR PANEL. D. A. Jaworske¹, M. A. Gibson¹, and D. S. Hervol², ¹NASA Glenn Research Center, 21000 Brookpark Road, Cleveland, OH, 44135, ²QinetiQ North America at NASA Glenn Research Center, 21000 Brookpark Road, Cleveland, OH, 44135.

Introduction: A titanium-water heat pipe radiator having an innovative proprietary evaporator configuration was evaluated in a large vacuum chamber equipped with liquid nitrogen cooled cold walls. The radiator was manufactured by Advanced Cooling Technologies, Inc. (ACT), Lancaster, PA, and delivered as part of a Small Business Innovative Research effort. The radiator panel consisted of five titanium – water heat pipes operating as thermosyphons, sandwiched between two polymer matrix composite face sheets. The five variable conductance heat pipes were purposely charged with a small amount of non-condensable gas to control heat flow through the condenser. Heat rejection was evaluated over a wide range of inlet water temperature and flow conditions, and heat rejection was calculated in real-time utilizing a data acquisition system programmed with the Stefan-Boltzmann equation. Thermography through an infrared transparent window identified heat flow across the panel. Under nominal operation, a maximum heat rejection value of over 2200 Watts was identified. The thermal vacuum evaluation of heat rejection provided critical information on understanding the radiator’s performance, and in steady state and transient scenarios provided useful information for validating current thermal models in support of the Fission Power Systems Project.

Background: For a 40 kWe Fission Power System (FPS) lunar-based installation, radiators would be needed to dissipate approximately 140 kWt of waste heat.¹ As part of the FPS technology development effort, a radiator panel was acquired from ACT.² The panel was a titanium – water heat pipe radiator panel consisting of two titanium manifolds to supply the hot water to the panel and five titanium – water heat pipes to distribute heat extracted from the hot water stream across the 2.94 m² polymer matrix composite panel. A photograph of the panel is shown in Figure 1. The heat rejection of the radiator panel was measured in the liquid nitrogen cooled thermal vacuum environment of NASA Glenn Research Center’s Vacuum Facility 6 (VF 6). Measuring performance under thermal vacuum is needed to validate thermal models and enable scaling to larger radiators in support of the Technology Demonstration Unit (TDU), which is a quarter scale system demonstration of a concept FPS.

Inlet water was provided to the radiator panel utilizing an existing circulating pressurized hot water

facility operating on city water. Given the short duration of the test, the need for deionized water was deemed unnecessary. New to the assembly was a Facility Cooling System (FCS) operated remotely via outlet water temperature set points entered into the data acquisition system. The FCS is an all stainless steel forced air heat exchanger located outside of the thermal vacuum chamber. Plumbed in line after the radiator panel and before the circulating pump, the FCS provided an efficient means of extracting heat from the water stream during cool down operations.

One unique panel feature is the heat pipe evaporator configuration. The panel consists of five titanium – water heat pipes that are thermally connected to the inlet hot water supply utilizing novel evaporators that should provide a minimal pressure drop in the hot water supply line. The minimal pressure drop is significant for two reasons. First, the initial thaw operation on the lunar surface will require a rush of water into the hot water supply lines. An unencumbered pathway is needed to provide a rapid throughput of water in the hot water supply lines before significant heat transfer can take place to the heat pipes themselves. Second, the minimal pressure drop drives down the size and energy requirements of the pumping system. The evaporators are in thermal contact with two titanium manifolds, three evaporators in thermal contact with the first manifold and two evaporators in thermal contact with the second. Typical of other radiators, this radiator was equipped with Poco foam graphite saddles and high thermal conductivity face sheets; however no thermal control coating was applied.³

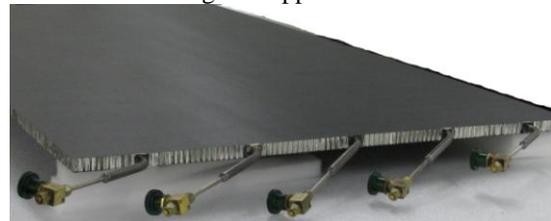


Figure 1. Radiator panel with five heat pipes.

The average emittance value of both facesheets was obtained utilizing a Gier-Dunkle DB-100 infrared reflectometer. Both face sheets were measured and the average emittance was utilized for the Stefan-Boltzmann heat rejection calculations. The as-measured emittance of the ACT radiator panel was found to be 0.83 ± 0.01 .

Two basic tests were considered, nominal and off-nominal operations. Normal steady state operation of the radiator was achieved over a range of water inlet temperatures and flow rates. Heat rejection was determined by utilizing the average surface temperature of the panel, the average sink temperature of the chamber, the known surface area of the panel, and the panel emittance, via the Stefan-Boltzman equation. Multiple water inlet temperatures between 300 and 420 degrees Kelvin were selected as set points throughout the test, achieved in ascending, descending, or randomized order. Three water flow rates were selected as set points throughout the test, 0.175, 0.375, and 0.750 kg/s, all of which were turbulent flow conditions. Steady state operation was typically achieved in approximately 30 minutes. No limit was placed on the system for cold soak operations, though care was taken to remove water from the manifolds prior to any anticipated cold soak.

Off-nominal operation was considered for evaluating the radiator panel for freeze – thaw performance. To accomplish this task, the water was drained from the waterlines and the radiator panel was allowed to cold soak. Once at steady state under cold soak, an ample volume of heated water was re-introduced into the waterlines, and back into the manifolds in contact with the evaporators, allowing the panel to return to a normal operating temperature.

Results and Discussion: Heat rejection was found to be linear with water inlet temperature, with one exception. One heat pipe exhibited the characteristics of a heat pipe having no non-condensable gas charge. One characteristic of such a heat pipe is that the water in the heat pipe can very easily freeze in the condenser upon cool down and be unavailable for subsequent use in the evaporator at the time of heat up. Infrared thermography revealed such a sequence of events for that one heat pipe on an early ascending water inlet temperature sequence. However, once the balance of the panel was warm, sufficient heat flowed through the polymer matrix composite face sheets to thaw the condenser of that heat pipe and normal operation resumed. Figure 2 summarizes radiated power as a function of water inlet temperature over multiple water flow rates, in ascending, descending, and randomized order. Temperature and power standard deviations are $\pm 0.2\%$ and $\pm 3\%$, respectively. Figure 3 is an infrared thermography image of the fully engaged panel, with the five heat pipe locations clearly identified.

Radiator panel freeze – thaw performance was found to be exceptional. Normal operation of the radiator panel resumed after cold soak. Infrared thermography after cold soak revealed no unusual heat flow within the panel, though again one heat pipe only op-

erated after thawing when the balance of the panel was warm.

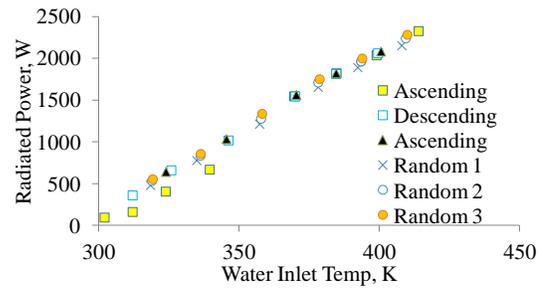


Figure 2. Heat rejection vs. water inlet temperature.

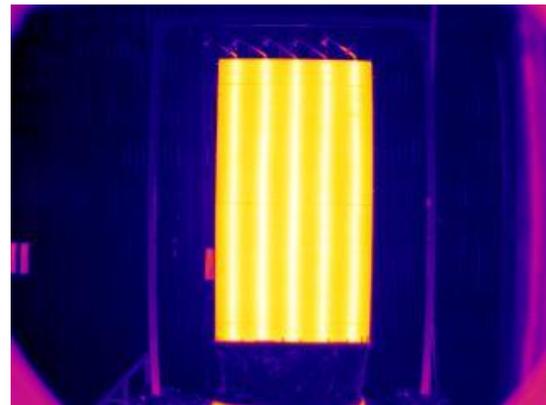


Figure 3. Infrared image of radiator panel in VF 6.

Conclusions: The heat rejection of a radiator panel composed of five variable conductance titanium – water heat pipes was evaluated under thermal vacuum conditions. The panel was successfully operated over a range of inlet water temperatures and flow rates, and was subjected to a cold soak and successfully returned to normal operation. Infrared thermography revealed that the non-condensable gas charge in one heat pipe was absent, and that heat pipe resumed normal operation once thawed by heat from the balance of the panel. Data gathered from the heat rejection testing will be relevant to radiator scale-up and modeling for future operation of a Technology Demonstration Unit.

References:

[1] Mason, L. (2009) *Proceedings of Nuclear and Emerging Technologies for Space 2009*, paper 204298.
 [2] Anderson, W. G., et al. (2006) *4th International Energy Conversion Eng. Conf.*, AIAA 2006-4146.
 [3] Jaworske D. A. and Sanzi, J. L., (2010) *8th International Energy Conversion Eng. Conf.*, paper AIAA 2010-6850 .

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